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Morphological Deformities in *Chironomus*, *Cryptochironomus*, and *Procladius* Larvae (Diptera: Chironomidae) from Two Differentially Stressed Sites in Tobin Lake, Saskatchewan

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Morphological deformities in *Chironomus plumosus* type larvae from two differentially stressed sites in the Tobin Lake reservoir are described and compared. The frequency of deformities was 41.3% at Site 2 where larvae are directly exposed to contaminants entering the reservoir from the Saskatchewan River. At Site 17, where larvae are only indirectly exposed in a backwater area, the frequency was 31.8%. The frequency of deformities was higher at Site 2 in all head capsule structures except antennae. At Site 17, the significantly higher frequency of antennal deformities suggests that (1) antennae respond to contaminants according to a quantal dose–response relationship, (2) antennae and other head capsule structures may respond through different mechanisms or at different rates, or (3) other environmental factors may modify larval responses to contaminants. Descriptions of the deformities in other head capsule structures provide a framework for individual indices of severity of deformation similar to that developed previously for antennae. These eventually will be incorporated into an Index of Total Morphological Response. Deformities in *Procladius* and *Cryptochironomus* larvae are also described.

Les auteurs décrivent et comparent les anomalies morphologiques de larves de l'espèce *Chironomus plumosus* provenant de deux emplacements du réservoir du lac Tobin perturbés de façon différente. La fréquence des anomalies a été de 41,3 % à l'emplacement 2 où les larves sont exposées directement aux contaminants apportés dans le réservoir par la rivière Saskatchewan. À l'emplacement 17, où les larves ne sont exposées qu'indirectement, se trouvant dans un secteur d'eaux dormantes, la fréquence a été de 31,8 %. La fréquence des anomalies de toutes les structures de la capsule céphalique à l'exception des antennes a été plus élevée à l'emplacement 2. À l'emplacement 17, la fréquence significativement plus élevée des anomalies des antennes donne à penser 1) que les antennes réagissent aux contaminants suivant une réaction positive ou nulle en fonction de la dose, 2) que les antennes et d'autres structures de la capsule céphalique peuvent réagir par des mécanismes différents ou à des taux différents, ou 3) que d'autres facteurs environnementaux peuvent modifier les réactions des larves aux contaminants. Des descriptions d'anomalies touchant d'autres structures de la capsule céphalique offrent la possibilité de déterminer des indices individuels de la gravité des déformations semblables à ceux établis précédemment pour les antennes. Ces descriptions seront intégrées éventuellement dans un indice de réaction morphologique totale. Les auteurs décrivent également les anomalies rencontrées chez les larves de *Procladius* et de *Cryptochironomus*.

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Although contaminants pose one of the most serious environmental problems facing society today, their chemical characteristics and probable impact can seldom be determined because of the complexity and expenditure involved. Thus, emphasis is shifting towards biological methods for assessing the severity of contamination. However, as yet there are few, if any, widely accepted and reliable methods available for detecting and assessing the impact of contaminants on biological communities residing in, and depending on, freshwater ecosystems (National Research Council of Canada 1985).

Warwick (1985) proposed using morphological deformities in chironomid larvae as a biological screening tool to detect and assess the impact of contaminants in freshwater ecosystems. Hamilton and Saether (1971) linked morphological deformities to contaminants because deformed larvae generally were found only in areas receiving industrial and/or agricultural contaminants, but not in areas polluted by domestic sewage. Subsequent observations by a number of authors (Saether and McLean 1972; Hare and Carter 1976; Warwick 1980a, 1980b, 1980c; Köhn and Frank 1980; Tennessen and Gottfried 1983; Wied-

erholm 1984; Cushman 1984; Warwick et al. 1987) support the Hamilton/Saether hypothesis. Warwick (1985) and Percy et al. (1986) presented experimental evidence confirming the linkage between contaminants and morphological deformities in chironomid larvae.

Warwick (1985) stressed the need to develop a framework within which the severity of morphological deformities could be assessed and used to gauge response. As a first step, he proposed a quantitative numerical index based on deformities in the antennae of larvae of *Chironomus* Meigen. The objectives of this paper are to (1) document the types of deformities in *Chironomus plumosus* type larvae from two differentially stressed sites in Tobin Lake, (2) explore the range of severity in these deformities and compare their distributions in the two faunas, (3) establish a framework for indexing the severity of deformation in additional morphological structures for eventual inclusion in an overall Index of Total Morphological Response for *Chironomus* larvae, and (4) begin similar documentation for *Procladius* and *Cryptochironomus* larvae.

Study Area

The materials used in this study came from Tobin Lake, east-central Saskatchewan (Fig. 1). Tobin Lake is a reservoir on the mainstem Saskatchewan River formed in 1960–63 by impoundment behind the Squaw Rapids hydroelectric dam. The reservoir is made up of two distinct basins: one parallels the original Saskatchewan River valley and the other includes the original Petaigan River valley and some bordering agricultural land. The greater part of the contaminant burden to the lake enters via the Saskatchewan River system. This includes agricultural and industrial residues from the greater part (270 000 km²) of the Canadian prairie provinces. The drainage basin of the Petaigan River is much smaller (466 km²), includes only agricultural lands, and probably contributes only a very small proportion, if any, of the contaminant burden to the reservoir. The exchange of waterborne materials between the two basins probably is limited by basin morphometry (Fig. 1). Heavy *Typha* beds also screen the two basins except where the deepwater channel connects.

Chironomid larvae were collected from two sites: one in each basin for purposes of comparison. Tobin Lake Site 2 is located (53°28′44″N, 103°50′51″W) in the deposition zone just below the inflow of the Saskatchewan River (Fig. 1). Benthic communities in this area are directly exposed to contaminants borne by the Saskatchewan River. Tobin Lake Site 17 is located (53°33′16″N, 103°28′16″W) in the former Petaigan River valley. Site 17 is influenced more by the intermittent flow of the Petaigan River than backflow from the main Saskatchewan system. Both sites were identified as primary sites for chemical, physical, and bioassay analysis in the original Tobin Lake project proposal (Birkholz et al. 1980).

Methods and Materials

Tobin Lake Sites 2 and 17 were sampled for benthos, water, and sediments on 8 and 15 February 1980. Each benthic sample included the contents of three tall 232-cm² Ekman grabs. The samples were sieved through 200-μm-mesh nets of Nitex nylon within 24 h of collection. Materials retained in the sieve were preserved in 70% ethanol, stained with Rose Bengal, and sorted. Sorted benthos were separated into individual taxa, enumerated, and preserved in fresh 70% ethanol for future analysis.

Preserved chironomid larvae were prepared and mounted in Canada balsam according to the methods described in Warwick

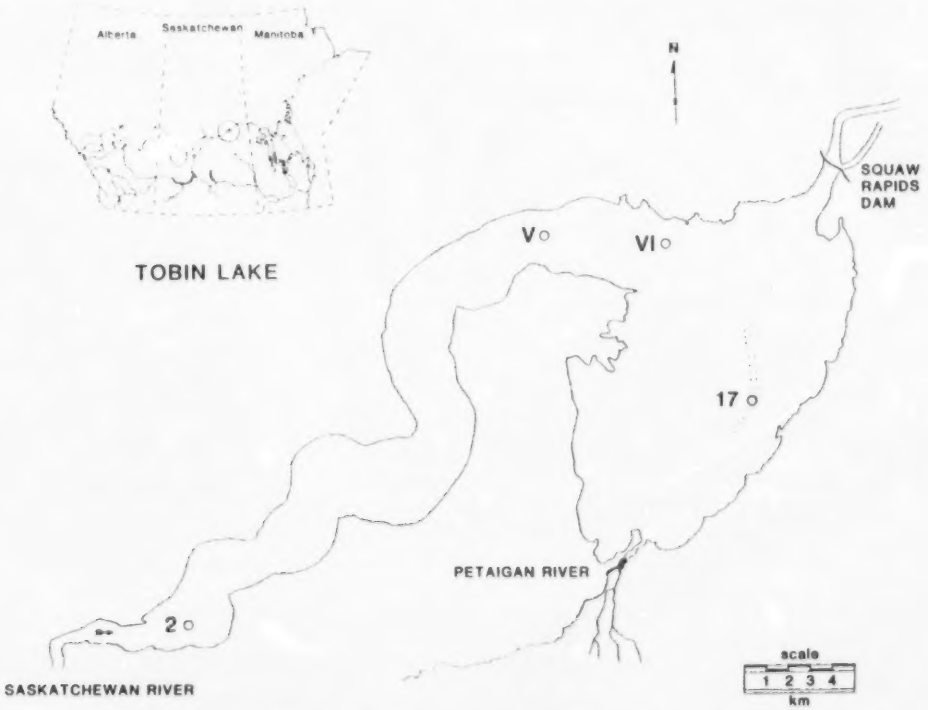

FIG. 1. Location of sampling sites in the Tobin Lake reservoir, February 1980.

TABLE 1. Comparison of chironomid faunas from Tobin Lake Sites 2 and 17.

	Site 2		Site 17	
	No.	%	No.	%
Chironomus plumosus type	482	41.5	153	31.4
Chironomus thummi type	5	20.0	0	0.0
Chironomus salinarius type	0	0.0	1	100.0
Procladius (Holotanypus) sp.	259	25.6	77	24.9
Procladius (Psilotanypus) bellus (Loew)	31	3.1	1	0.3
Procladius spp.	54	5.4	19	6.1
Cryptochironomus sp.	123	12.2	45	14.6
Other taxa	56	5.5	13	4.2
Total	1010		309	

(1980a, 1985). These methods permit the examination of fine morphological detail using high-power, oil-immersion objectives. No attempt was made to identify larvae to species because of the problems involved in the identification of chironomid immature stages (cf. Lindeberg and Wiederholm 1979).

In this study, morphological deformities were found in the antennae, mentum, mandibles, premandibles, epipharyngeal pecten, labral lamellae, and labral setae. These deformities were categorized according to the following framework: (1) *antennal deformities* according to (a) the loss or fusion of individual segments, (b) the loss or displacement of auxilliary sensory structures, (c) reduction in the length of any or all segments, and (d) the presence of structures of unknown equivalence following Warwick (1985); (2) *mentum deformities* occurring in (a) the tripartite median teeth, (b) the two large, inner lateral teeth, (c) the four smaller, outer lateral teeth, and (d) those occurring generally throughout the mentum or (e) showing asymmetry or massive disorganization of the basic configuration; (3) *mandible deformities* involving (a) the number of subapical or apicodorsal teeth, (b) the conformation of the apical tooth, (c) the presence, form, and pattern of the spurs, setae, and pecten and (d) the general configuration of the mandible; (4) *premandible deformities* involving (a) the number of apical teeth, (b) the configuration of individual teeth, and (c) the general configuration of the premandible; (5) *deformities in the epipharyngeal pecten* showing (a) fusing, (b) overlapping, (c) stunting, and (d) disjunction of the epipharygeal structure; (6) deformities in the *labral lamellae* involving (a) division along the median suture line, (b) reduction in size (in whole or in part), (c) malformation of individual lamella, and (d) duplication and overlapping of individual sets of lamellae; and (7) deformities in *labral setae* involving departure from the normal plumose configuration.

The frequency of deformities was determined as the ratio of the number of actual to possible occurrences expressed in percent. The term "frequency" (sensu "prevalence"; Margolis et al. 1982) replaces the term "incidence" used in Warwick (1985, 1988).

The severity of antennal deformations was assessed according to Warwick (1985); no attempt has been made at this time to assess the severity of deformities within the framework proposed for the other structures outlined above.

Results

Chironomid Community Comparisons

The chironomid communities at Sites 2 and 17 were dominated by *Chironomus*, *Procladius*, and *Cryptochironomus* larvae (Table 1). The highest frequencies of deformities were in *Chironomus* larvae. At Site 2, 41.3% of *Chironomus* larvae were deformed compared with 31.8% at Site 17. The frequencies of deformities in *Procladius* and *Cryptochironomus* larvae were an order of magnitude less. In *Procladius* larvae, the frequencies of deformities were 4.4 and 2.1% at Site 2 and 17, respectively, and in *Cryptochironomus* larvae were 4.9 and 6.7% at Site 2 and 17, respectively. The data for *Cryptochironomus* should be regarded as tentative at this time because the information available to interpret the response of this genus is still very limited.

A comparison with the frequency of deformities in a chironomid population of very similar composition from Last Mountain Lake, south-central Saskatchewan, is useful to set these results in context. Last Mountain Lake Site I is located in the southern end of Last Mountain Lake and is contaminated by river water shunted back up into the lake from the Qu'Appelle River system during spring flooding (Warwick 1985). These events are periodic and usually of short duration when they do occur. In Site I, the frequencies of deformities in *Chironomus*, *Procladius*, and *Cryptochironomus* larvae was 16.2, 1.5, and 0.8%, respectively (W. F. Warwick, unpubl. data). Compared with this mildly contaminated site, the frequencies of deformities were more than twice as high in most cases at both Tobin Lake sites.

Also by way of comparison, Warwick (1985) reported that the frequency of deformities in cultures of *Chironomus tentans* Fab. held under controlled laboratory condition was 1–2%. Similar frequencies were recorded from populations of *C. riparius* maintained under laboratory conditions (Frank 1983).

Description of Morphological Deformities in *Chironomus plumosus* Type Larvae

1. Normal and deformed antennae

The five-segmented antenna of normal *Chironomus* spp. larvae (Fig. 2a) is a complex sensory organ bearing multiple sensillae which serve in mechano- and chemoreceptor roles. The conjoined blade and accessory blade and the peg sensillae probably are chemoreceptors and the ring organ, basiconic sensillum, style, and organs of Lauterborn probably serve as mechanoreceptors. The function of these receptors was discussed in detail in Warwick (1985).

The antennal deformities found in Tobin Lake Sites 2 and 17 display much the same range of deformities described in Warwick (1985). The more obvious deformities involve the loss of individual segments (Figs. 2d, 2f), the fusion of one or more adjacent segments (Fig. 2c), or the presence of segments of questionable equivalence (Figs. 2c, 2e, 2g). The antenna in Fig. 2b is unusual in having an additional (6th) segment appended along the side of the penultimate (4th) segment. Individual antennae in many cases are reduced in length; these reductions can occur generally or be confined to basal, distal, or individual segments (Fig. 2f). In some cases, the ring organ may be displaced or entirely lacking. Other sensory organs such as the blade/accessory blade complex or the style may be displaced from their normal positions at the apices of the first (Fig. 2h) or second segment, respectively. In some cases, the apical segments are lost (Figs. 2i, 2j) and only remnants of the sensory structures remain (Figs. 2k, 2l) or the apices of the basal segment are completely fused over (Fig. 2m). In more unusual cases, structures appear for which no homology is known. These may range from simple protuberances to complex trident- or palmate-shaped structures (Warwick 1985).

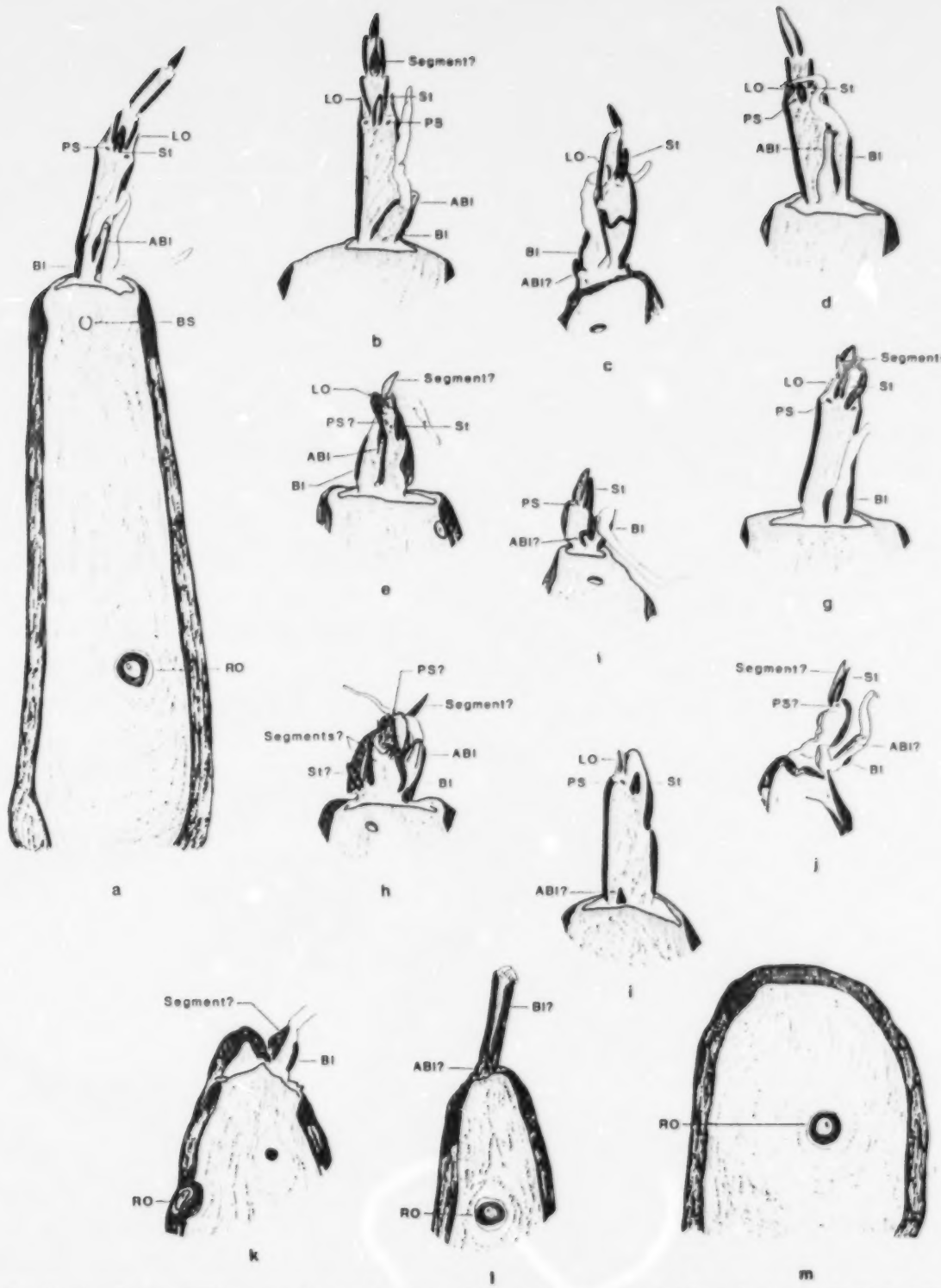

FIG. 2. Deformities in antennae of *Chironomus plumosus* type larvae: (a) normal antenna; (b–m) deformed antennae. BI, blade; ABI, accessory blade; St, style; PS, peg sensillum; LO, organs of Lauterborn; BS, basiconic sensillum; RO, ring organ.

2. Normal and deformed menta

The mentum is a double-walled medioventral plate (Fig. 3a) consisting of the dorsomentum and ventromentum in which the latter extends laterally into the ventromental plates (Saether 1980). The mentum has 15 darkly pigmented teeth made up of a tripartite median arrangement of one large tooth flanked on either side by single smaller teeth and two larger and four smaller outer teeth on either side. The heavily pigmented pat-

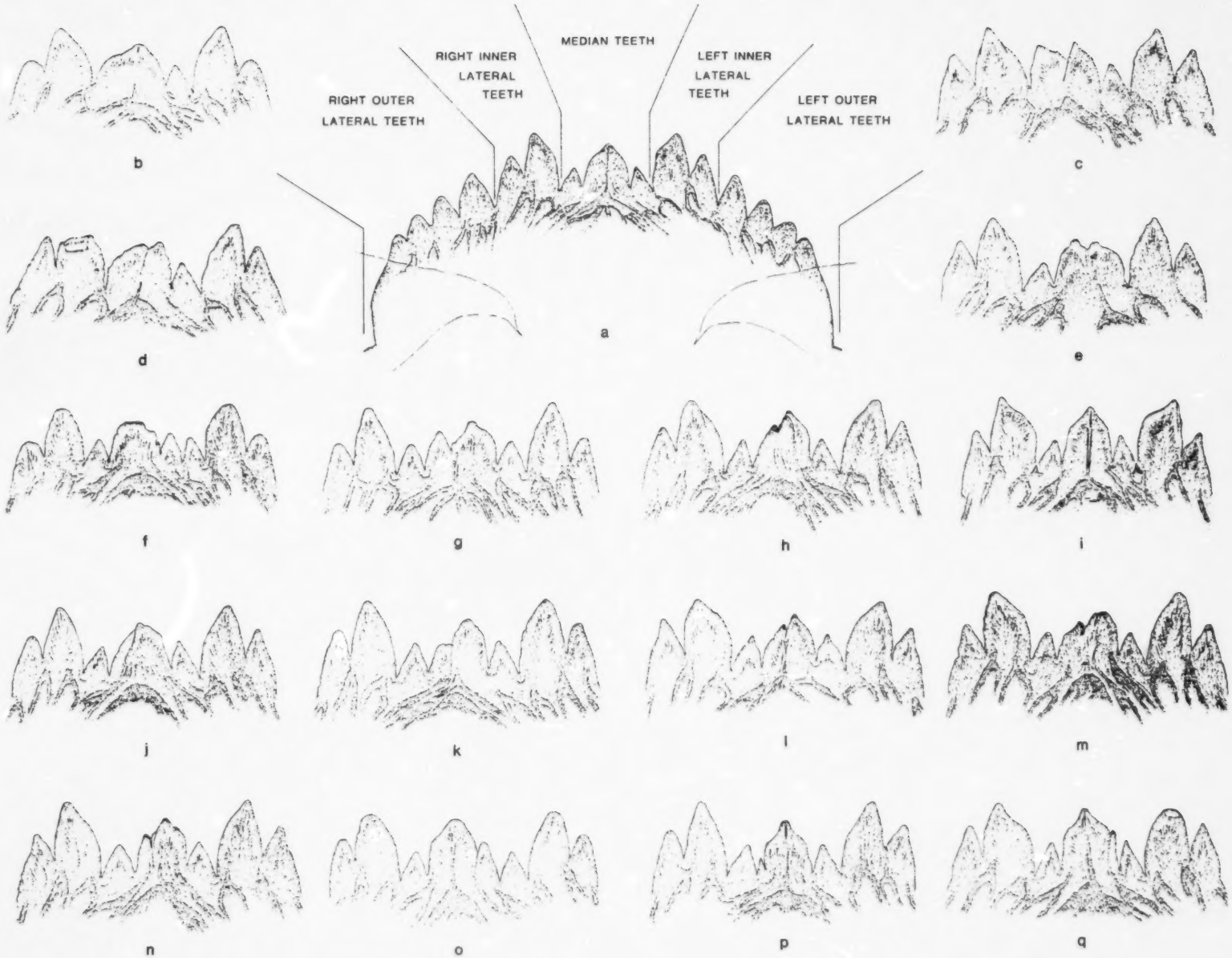

FIG. 3. Deformities in the median teeth of the mentum of *Chironomus plumosus* type larvae: (a) normal median teeth; (b–q) deformed median teeth.

terns extending below the teeth suggest areas of thickened chitinous reinforcement for the teeth. The ventromenta of *C. plumosus* type larvae are characteristically marked by a curved row of fascia-like bundles of stria located just below the anterior margin.

Deformities in the mentum can be divided into five basic categories: (a) those occurring in the three median teeth, (b) those occurring in the two larger, inner lateral teeth, (c) those occurring in the four smaller, outer lateral teeth, (d) those occurring generally throughout the mentum, and (e) those showing asymmetry or massive disorganization in basic configuration.

(a) Median deformities — The number of teeth in the median area of the mentum can vary from the normal tripartite arrangement to menta with two, three, four, and five median teeth (Fig. 3). An example with two teeth is shown in Fig. 3b. In this case, one of the smaller side teeth is missing. The examples in Fig. 3c and 3e have three teeth, but one of the smaller side teeth is enlarged. The example in Fig. 3d might be mistaken for three teeth, but the pattern of stria on the teeth indicates that the larger tooth is split rather than a third tooth being present as in Fig. 3e. Examples with four and five median teeth are shown in Fig. 3f–3i. In Fig. 3i, the extra teeth are represented by two tiny teeth symmetrically sited submarginally at the junction of the median and first lateral teeth. As many as eight median teeth have been found in deformed larvae from other sites (Warwick 1980c).

The remaining examples in Fig. 3 show some of the range of variability that can occur in median areas having four teeth. The separation of the fourth tooth becomes progressively more apparent between Fig. 3j, where the smaller central tooth overlaps the larger tooth, and Fig. 3o, where each tooth is well separated. The additional tooth may also be quite small and located at the base (Fig. 3p) or on the shoulder (Fig. 3q) of the central tooth.

The central teeth in the menta in Fig. 4 are reduced in size (Fig. 4b, 4c), malformed (Fig. 4d, 4e), and split (Fig. 4f–4i). In the classical sense, splitting in the median tooth usually is symmetrical (Fig. 4h). In specimens from other sites, examples have been found where splitting has penetrated to the base of median tooth (W. F. Warwick, unpubl. data). The divergent pattern of stria on these teeth shows that they represent single teeth that have been split rather than two separate teeth. The mechanism of formation clearly differs from that producing the extra median teeth shown in Fig. 3.

Although less frequently observed, a number of central teeth displayed (Fig. 4j–4l) the crusting typical of larvae from lakes forming the Southern Indian Lake–Notigi Reservoir system which were affected by mercury contamination (Bodaly et al. 1984). These encrustations appear as small darkened areas along the outer margins of the teeth. The margins of these teeth wear unevenly suggesting that the darkened areas are harder than the surrounding lighter areas. This is particularly apparent in Fig. 4l. The central tooth in this illustration is also deeply split.

A number of specimens displayed characteristic "Köhn" gaps in the median area of the mentum. These gaps were characteristic of *Chironomus thummi* larvae collected from the heavily polluted Teltowkanal in Berlin, Germany (Köhn and Frank 1980). True gaps can be identified by the lack of colour and support ribbing underlying the area of the gap itself. The presence of the gap may (Fig. 4o) or may not (Fig. 4m, 4n) involve the loss of one or more of the tripartite median teeth.

Several larvae had characteristic "keyhole" openings in the central tooth (Fig. 4p, 4q). Similar, but somewhat more bizarre specimens of this type have been found in larvae from Crooked Lake, Saskatchewan (W. F. Warwick, unpubl. data).

(b) Inner lateral deformities — The number of inner lateral teeth may be increased (Fig. 5b, 5c) or reduced (Fig. 5d) to single teeth. The two lateral teeth can also be incompletely separated (Fig. 5e–5g) to form bifid first lateral teeth. Intermediate examples can intergrade to the point where bifid first laterals and those with three inner lateral teeth can be difficult to separate.

(c) Outer lateral deformities — The number of outer lateral teeth may also be increased (Fig. 5h) by additional teeth or reduced to three (Fig. 5j, 5i) or two (Fig. 5l, 5k) outer lateral teeth. Examples with only one outer lateral tooth have not yet been found, but the number of additional teeth can achieve startling proportions; larvae with 39 (total 48) and 48 (total 57) additional teeth have been found in samples from Tobin Lake and the former Rat Lake basin of the Southern Indian Lake – Notigi Reservoir, respectively (W. F. Warwick, unpubl. data).

Examples of additional teeth in the form of small, sublaterally mounted teeth were also found (Fig. 5m–5o). In contrast with the additional tooth in Fig. 5h which was full-sized and in line with the other outer lateral teeth, these teeth were less well-formed, occurred singly (Fig. 5m, 5n) or in pairs (Fig. 5o), and were variously positioned along the outer lateral margin of the mentum. Similar rudimentary teeth were noted above (Fig. 3i) in the central area of the mentum.

Teeth can also overlap one another. In the outer lateral teeth, overlapping usually occurs between the fourth, fifth, and sixth teeth (Fig. 5p, 5q), but other combinations have been found. Classic overlapping is readily distinguished from some normal specimens in which the fifth tooth tends to appear separate.

(d) Integral deformities — These refer to deformities that are not identified with specific areas of the mentum, but apply to the mentum in general. Structural weakening of the mentum shown by the lack of colour and wearing in individual teeth (Fig. 5r–5u) would fall into this category. The three outer teeth in Fig. 5r are unusual in that they are almost colourless and yet are intact. Usually such teeth are badly worn (Fig. 5s) or worn away completely (Fig. 5t). The latter can be difficult to distinguish from normal teeth that have been broken by other means, but usually there is enough of the light-coloured area remaining to make the determination reliably. If there is not, the conservative approach would be to disregard the specimen as broken by natural causes. Teeth of this type can appear in the inner lateral (Fig. 5u) or central (Fig. 4r) teeth as well.

The interpretation of poor structural strength is based on data from preliminary dose–response experiments using DDE (W. F. Warwick, unpubl. data). *Chironomus tentans* larvae with colourless menta were found in cultures exposed to 10 μg $DDE \cdot L^{-1}$. The granular, sugar-like texture of these menta gave little impression of strength and all were badly worn.

(e) Basic Configuration — The deformities discussed independently above can appear in combinations of increasing severity (Fig. 6a–6l) which can lead to individuals whose menta bear little resemblance to the basic configuration. For example, the mentum in Fig. 6a has four median teeth and one inner lateral tooth. The example in Fig. 6b is similar, but the configuration of the median teeth differs slightly. The mentum in Fig. 6c also has four median teeth, but only three outer lateral teeth are present. In Fig. 6d, the mentum has four median teeth, one pale-coloured outer lateral tooth, and one smaller, subla-

FIG. 4. Deformities in the median teeth of the mentum of *Chironomus plumosus* type larvae: (a) normal median teeth; (b–r) deformed median teeth.

terally mounted tooth. The example in Fig. 6e has three lateral teeth on the right side of the mentum and only single inner lateral teeth, the one on the right of which is considerably enlarged. The central tooth in Fig. 6f is split, one inner lateral (left) is missing, and both large inner lateral teeth are bifid. The example in Fig. 6g has four median teeth, a single bifid inner lateral tooth, and evidence of some asymmetry on the left side. The asymmetry is more pronounced in Fig. 6h where the men-

FIG. 5. Deformities in inner and outer lateral teeth of the mentum of *Chironomus plumosus* type larvae: (a) normal inner and outer lateral teeth; (b–u) deformed inner and outer lateral teeth.

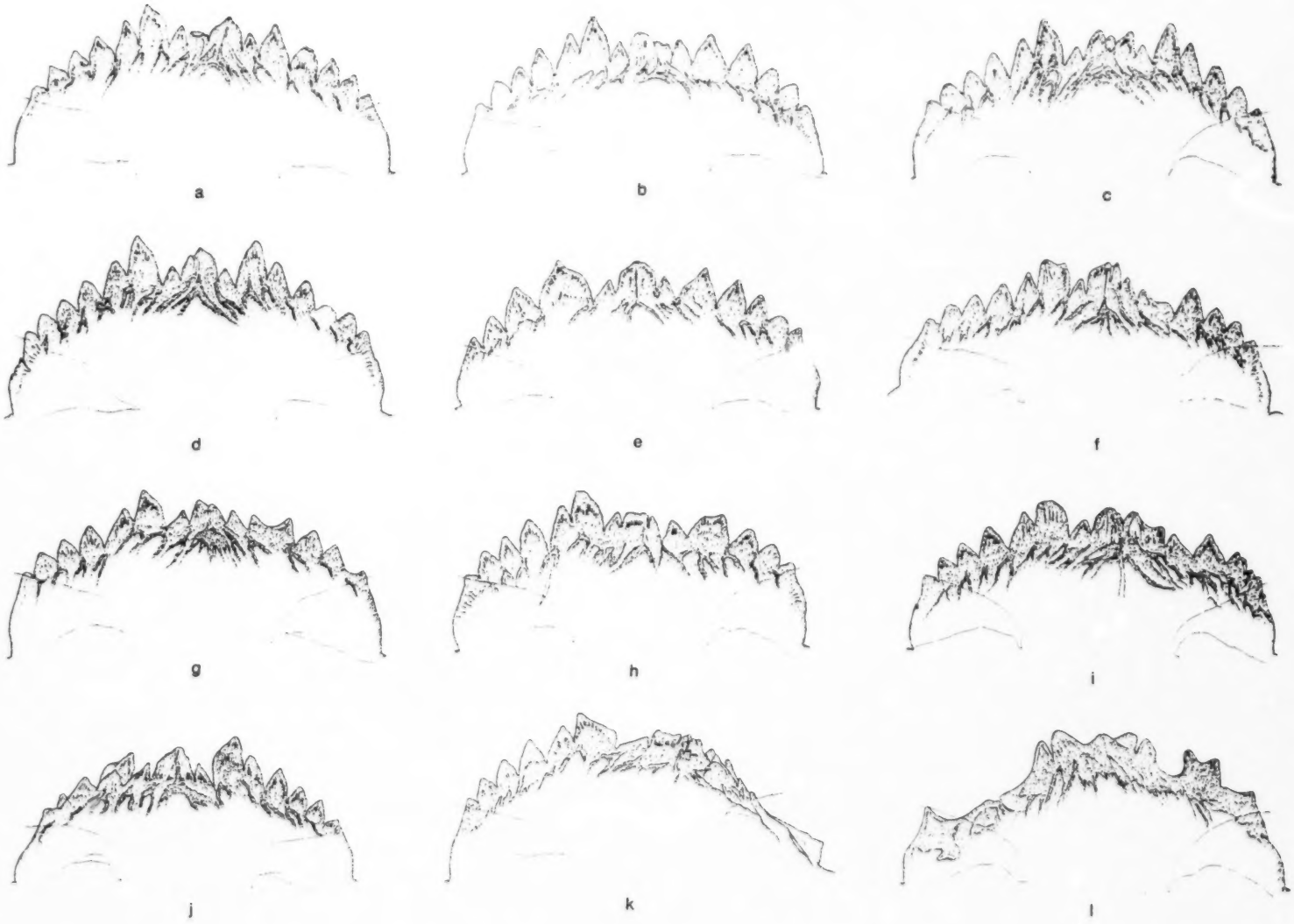

FIG. 6. Deformities in the menta of *Chironomus plumosus* type larvae: deformed menta displaying various combinations of deformity types.

FIG. 7. Deformities in the mandibles of *Chironomus plumosus* type larvae: (a) normal mandible; (b–l) deformed mandibles. AT, apical tooth; AdT, apicodorsal tooth; AdS, apicodorsal spur; ExS, external seta; SMM, sensillum minusculum; LS, lateral seta; RO, ring organ; Si, setae interna; BaS, basal spurs; Mo, mola; SaS, subapical spurs; SSd, seta subdentalis; PMa, pecten mandibularis; SaT, subapical teeth.

tum has four median teeth, a single enlarged inner lateral tooth, and three outer lateral teeth. The left side of the mentum in Fig. 6i is more seriously deformed; there is one sublateral tooth, five overlapping outer lateral teeth, one inner lateral tooth, and four median teeth, one of which is bifid and another of which is superimposed. The right side of the mentum in Fig. 6j has four lateral teeth which not only overlap in themselves, but also overlap the single inner lateral tooth. The central tooth is also mildly asymmetrical. The mentum in Fig. 6k is severely deformed; there are 14 teeth representing the left-medial part of the mentum for a total complement of 20 teeth. The mentum in Fig. 6l is so severely deformed that verbal descriptions become quite inadequate.

3. Normal and deformed mandibles

The mandibles of normal larvae are heavily sclerotized structures (Fig. 7a) located laterally on either side of the mouth. The apical half is usually attenuated with an apical tooth, three subapical or inner teeth linearly along the inner mesal margin, and a single dark apicodorsal or outer tooth on the outer margin. On *C. plumosus* type larvae, all mandibular teeth characteristically are dark brown to black. One, sometimes two, and, infrequently, three dark spurs are located inwardly below the apicodorsal tooth, while the blade-like seta subdentalis arises immediately below the inner teeth of the mandible. The pecten mandibularis, a comb of stiff, straight setae, angles distad across the distal mesal side of the mandible. The setae interna, a tuft of (usually three) branched setae, is located on the inner dorsomedial side below the mola, a weakly sclerotized area of the mandible. One to three sharply hooked basal spurs, often masked by the setae interna, are located on the ventromedial corner of the mandible. A large ring organ, probably a mechanoreceptor, is located ventrolaterally at the base of the mandible. One or two subapical spurs occur at the base of the seta subdentalis. In *C. plumosus* type larvae, these are small and bluntly triangular compared with the longer, more pronounced spurs in other *Chironomus* type larvae. The sensillum minusculum is a tiny sensilla located ventrolaterally on the mandible just lateral to the long external seta near the angle of the convex edge. The mandible probably functions in food gathering.

Mandible deformities generally involved the numbers of subapical and apicodorsal teeth, conformation of the apical tooth, the presence, form, and pattern of the spurs, setae, and pecten, and the general morphology of the mandible. Compared with the normal configuration (Fig. 7a), the mandibles in Fig. 7b and 7c have two and four subapical teeth, respectively. The mandible in Fig. 7d has three subapical teeth, but two are superimposed rather than on the same plane. Only one subapical tooth remains on the mandible in Fig. 7e; the apical tooth in this example appears proportionately longer, possibly because only one subapical tooth remains, but the longer apical teeth in the mandibles in Fig. 7f and 7g, each of which have two subapical teeth, suggest that the apical tooth can undergo a process of elongation. In contrast, the subapical teeth may also move distad rather than basally to leave a progressively wider gap between the base of the subapical teeth and the medial margin. This is clearly shown in Fig. 7h–7l. The same phenomenon is evident whether three (Fig. 7i), two (Fig. 7h, 7j, and 7l), or only one (Fig. 7k) subapical tooth remains.

The more strongly deformed mandibles diverge not only in the numbers of teeth, but in conformation and patterns of the spurs, bristles, and setae and in the general morphology of the mandible. The number of subapical teeth greatly increase from four (Fig. 8b) to 11 and 16 (Fig. 8a and 8e, respectively). Similarly, the number of apicodorsal teeth can increase from two (Fig. 8a, 8b) to four, five, six, eight, and nine (Fig. 8i, 8c, 8g, 8d, and 8h, respectively). The pecten on the mandibles in Fig. 8e, 8c, 8d, 8g, and 8i are irregularly patterned and misshapen as are the apicodorsal spurs. The mandible in Fig. 8a has two complete parallel rows of mandibular pecten and the distal end of the mandible is elongate and misshapen. The apices of the mandibles in Fig. 8g, 8h, and 8i are greatly elongate whereas those in Fig. 8f, 8k, and 8j are strongly reduced. The mandible in Fig. 8l is blunted, heavily fused, and the teeth greatly reduced and overlapping.

4. Normal and deformed premandibles

Premandibles are movable, inwardly curved appendages (Fig. 9a) located on either side of the ventral surface of the labrum attached to the tormal bar. Each has two apical teeth, or rami, identified herein as *a* and *b* for purposes of discussion, and a brush of small microtrichia, the premandibular brush, on the mesal margin (Saether 1980). The premandible probably functions in food manipulation.

Premandible deformities involve the number of apical teeth, the configuration of the premandible as a unit, and/or the configuration of individual teeth. Premandibles with a single tooth (Fig. 9e) probably are the most common form of deformity in the premandible, but examples with up to five teeth (Fig. 9r, 9s) have been found. The progression toward the single tooth configuration can proceed either through the loss of the *a* or *b* tooth or the fusion of both teeth. The remnant of the slender *a* tooth in Fig. 9b is gradually lost in Fig. 9c and 9d to the point where distinguishing between double- and single-toothed premandibles becomes problematic. Alternatively, in Fig. 9i–9l, the inner *b* teeth are much shorter than normal. Both teeth on the premandibles in Fig. 9f and 9g are shorter than normal. This progression seems to proceed toward the single-tooth configuration in Fig. 9h or the loss of both teeth in Fig. 9m. In the latter example, only remnants of the two teeth remain and the premandible is strongly atrophied.

The configuration and number of teeth can also vary. The premandibles in Fig. 9n and 9o each have three teeth, but in the latter, the third tooth is superimposed on the *b* tooth rather than being in line with the *a* and *b* teeth as in Fig. 9n. The premandible in Fig. 9l has a long dark structure projecting distally from the basal area of the teeth. This may represent a third tooth, but this seems doubtful. The premandibles in Fig. 9p and 9q have four teeth whereas those in Fig. 9r and 9s have five. In the latter example (Fig. 9s), the teeth are badly misshapen and atrophied.

5. Normal and deformed epipharyngeal pecten

The epipharyngeal pecten is a shallow U-shaped, transverse, toothed bar (Fig. 10a) located directly behind the labral margin between the tormal bar and ungula. The strongly shaped teeth generally increase in size from the outer margins inwards towards the center. Its function is unknown although it probably is involved in food manipulation.

Deformities in the epipharyngeal pecten range from fusing of the teeth to overlapping, asymmetry, stunting, and disjunction of the epipharyngeal structure. Fusion can begin with the junction of two central (Fig. 10b, 10c) or lateral (Fig. 10h, 10i) teeth and progress to the point where the central (Fig. 10g) and/or outer (Fig. 10m) teeth resemble scales rather than teeth. Overlapping can range from simple overlapping of individual teeth (Fig. 10n) to more extensive overlapping (Fig. 10p, 10q).

FIG. 8. Deformities in the mandibles of *Chironomus plumosus* type larvae: strongly deformed mandibles.

The transverse bar of the pecten can become progressively disjointed into two (Fig. 10r, 10s), three (Fig. 10t, 10u), and even four (Fig. 10v) individual sections which may overlap one another or be completely separated. In Fig. 10w, the transverse bar is separated into three distinct, coarsely toothed units. It is interesting to note that this arrangement and the broadly fused scale-like teeth in Fig. 10g and 10m suggest a trend towards the evolutionarily more primitive arrangement of three median

FIG. 9. Deformities in the premandibles of *Chironomus plumosus* type larvae: (a) normal premandible; (b–s) deformed premandibles. AP, articulating process; PmB, premandibular brush.

FIG. 10. Deformities in the epipharyngeal pecten of *Chironomus plumosus* type larvae: (a) normal epipharyngeal pecten; (b–ee) deformed epipharyngeal pecten.

scales in the epipharyngeal pecten (Saether 1980). (It is interesting to speculate whether or not contaminants promote reversion back to the more primitive condition.) The development of the pecten in Fig. 10z, 10aa, and 10bb is asymmetrical whereas in Fig. 10cc, 10dd, and 10ee, the pecten appear atrophied, withered, and undersized.

FIG. 11. Deformities in the labral lamellae and labral setae of *Chironomus plumosus* type larvae: (a) normal labral lamella; (b–r) deformed labral lamellae; (s) normal labral seta; (t–w) deformed labral setae. LLk, knuckle of labral lamella; LLs, spines of labral lamellae.

6. Normal and deformed labral lamellae

The labral lamella is a single, shallow V-shaped pectinate structure (Fig. 11a) located between the SI labral setae and the tormal bar (Saether 1980). Except at the extreme corners, the long, slender spines fringing the thickened knuckle of the lamella are generally uniform in length. Its function is unknown although it may possibly be sensory.

Deformities in the labral lamellae involve division along the

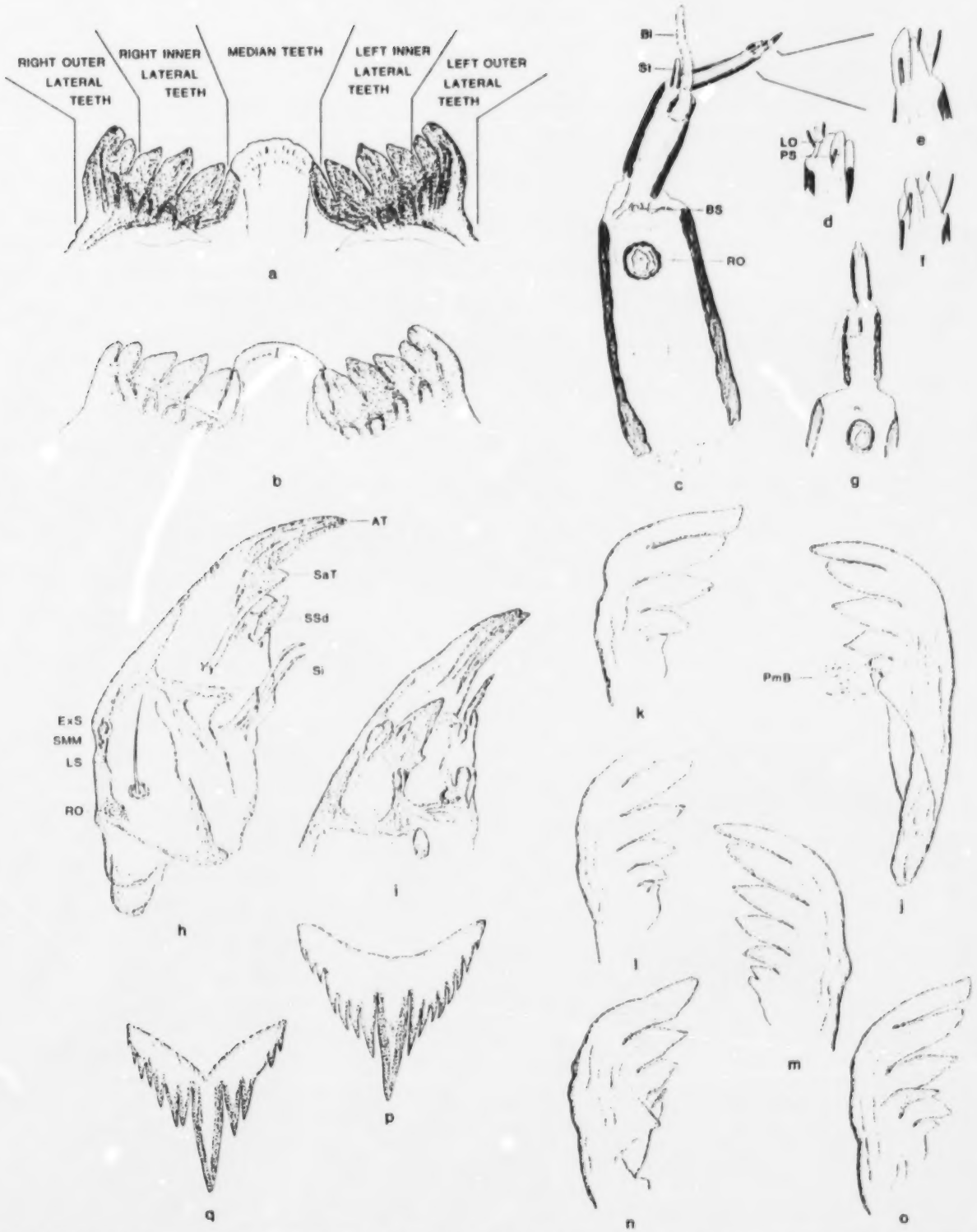

FIG. 12. Deformities in *Cryptochironomus* spp. larvae: (a) normal mentum; (b) deformed mentum; (c) normal antenna (with segment enlargements d–f); (g) deformed antenna; (h) normal mandible; (i) deformed mandible; (j) normal premandible; (k–o) deformed premandibles; (p) normal epipharyngeal pecten; (q) deformed epipharyngeal pecten. Bl, blade; St, style; PS, peg sensillum; LO, organs of Lauterborn; BS, basiconic sensillum; RO, ring organ; AT, apical tooth; SaT, subapical teeth; SSd, seta subdentalis; Si, setae interna; ExS, external seta; SMM, sensillum minusculum; LS, lateral seta; PmB, premandibular brush.

median suture line, reduction in size (in whole or in part), malformation of individual spines, and/or duplication and overlapping of individual sets of spines. Division of the lamella into two halves or "sets" is only partially complete in Fig. 11b, but in Fig. 11c and 11d, separation is complete. In Fig. 11c, the left half or "set" is much reduced in size compared with its counterpart, but in Fig. 11d, both are reduced. The lamella in Fig. 11e is symmetrical and bears both support arms, but it is strongly U-shaped and reduced in size. In contrast, the progressively smaller lamellae in Fig. 11f–11k are asymmetrical and appear to represent the development of only one half or "set" of the lamella.

The labral lamellae in Fig. 11l, 11m, and 11n appear incompletely divided into two or three sets of spines. In each example, irregular and abnormally shaped spines are present. In Fig. 11o, the lamella is symmetrical, but reduced in size and many of the spines are bifid.

The lamellae in Fig. 11p, and 11r are composed of numerous sets (two, three, and seven, respectively) of spines overlying one another. The sets are drawn separately to avoid confusion, with only the knuckle of the overlying sets outlined to show their superior position.

7. Normal and deformed labral setae

The anterodorsal part of the labrum bears four pairs of setae. Only the first pair, the SI, are noted here. The SI in *C. plumosus* type larvae are plumose with branches extending only partially down the outer side of the seta (Fig. 11s). Saether (1980) referred to the SI's as sensilla chaetica which suggests a mechanoreceptor role.

Deformities in SI labral setae vary widely from the mildly deformed example in Fig. 11t to the bizarre manifestation shown in Fig. 11w. Unless the specimen is carefully mounted, these types of deformities are difficult to detect.

Description of Morphological Deformities in *Cryptochironomus* Larvae

1. Normal and deformed antennae

The five-segmented antennae of *Cryptochironomus* differ (Fig. 12c) somewhat from that of *Chironomus* in that most of the sensillae which serve in mechano- and chemoreceptor roles are advanced distally by one segment. The organs of Lauterborn and peg sensilla are located between the third and fourth antennal segments. The peg sensilla is a long, post-like structure which frequently is difficult to see. There appears to be only one and this is shielded by two (enlargement Fig. 12e) or three (enlargement Fig. 12d, 12f) scale-like organs of Lauterborn. The heavier shielding around this fragile sensory organ possibly reflects an adaptation for the predatory lifestyle of *Cryptochironomus* larvae. The style is located between the third and fourth segments, while the blade is located subapically on the second segment. There appears to be no conjoined accessory blade as in *Chironomus*. A basiconic sensillum and ring organ are present on the basal segment. The single deformed antenna in Fig. 12g lacks distal segments IV and V and the style.

2. Normal and deformed menta

The mentum (Fig. 12a) has 15 teeth. The large central tooth is pale in colour and is flanked by smaller, closely conjoined dark teeth on either side. There are three larger inner lateral teeth on each side and three smaller outer lateral teeth, the outer two of which frequently appear only partially split. The dark concave outer teeth are also directed inwardly towards the large cutting edge of the central tooth, possibly another adaptation for its predatory role. The deformed mentum in Fig. 12b has two rather than three outer lateral teeth on the right side of the mentum.

3. Normal and deformed mandibles

The mandible of *Cryptochironomus* (Fig. 12h) has a single heavily sclerotized apical tooth flanked by two smaller dark subapical teeth. The seta subdentalis is spatulate and strong, while the mandibular brush is represented by a single heavy setae (Curry 1958). The setae internae are strong and barbed. A ring organ, lateral and external setae, and setae minusculum occupy the ventrolateral quadrant of the mandible.

In the badly deformed mandible in Fig. 12i, the two subapical teeth of the normal mandible have been replaced by four or five laterally located, misshapen teeth. Small blunted appendages also appear where the setae internae (Si) and mandibular brush should be located.

4. Normal and deformed premandibles

The premandibles of normal fourth instar larvae of *Cryptrochironomus* are equipped with six teeth and a premandibular brush along the inner margin (Fig. 12j). Deformed premandibles with five (Fig. 12k) and seven (Fig. 12l, 12m) teeth were frequently observed. Examples in which one of the six teeth was superimposed (Fig. 12n, 12o) appeared less frequently.

5. Normal and deformed epipharyngeal pecten

The epipharyngeal pecten is a single, triangular-shaped scale margined along two sides by small, sharp teeth terminating in one strong apical tooth (Fig. 12p). The deformed epipharyngeal pecten in Fig. 12q lacks a number of small teeth laterally and is deeply indented along the back margin.

Description of Morphological Deformities in *Procladius* Larvae

1. Normal and deformed antennae

The antenna of *Procladius* has four segments (Fig. 13n), the basal segment of which is much longer than the apical segments (enlargement Fig. 13o). The ring organ is located roughly 0.75× from the base of the basal segment. No basiconic sensillum appears to be present.

The antennal blade and conjoined accessory blade are located on the apex of the basal segment (enlargement Fig. 13p). Also located in this position are two tiny, dark-coloured, crescent-shaped structures similar to the structures located between the third and fourth segments on *Chironomus* antennae. Warwick (1985) suggested that these structures were peg sensilla. From their shape, these may be the same structures on *Procladius* antennae.

There are three structures located on the apex of the second segment (Fig. 13p). The structure of the larger of the three is very similar to the style on *Chironomus* antennae and probably serves the same function. The smaller two (referred to as sensory pegs SP_1 and SP_2 in Roback 1980) appear tube-shaped and heavy-walled. Each is mounted independently on individual pedestals rather than on the articulating membrane linking segments two and three. This would seem to rule out a mechanoreceptor role similar to that proposed for the organs of Lauterborn in *Chironomus* (Warwick 1985). Their structure more likely suggests a chemosensory role. According to Slifer (1970), thick-walled receptors of this type serve as contact chemoreceptors sensitive to stronger chemical stimuli. This interpreta-

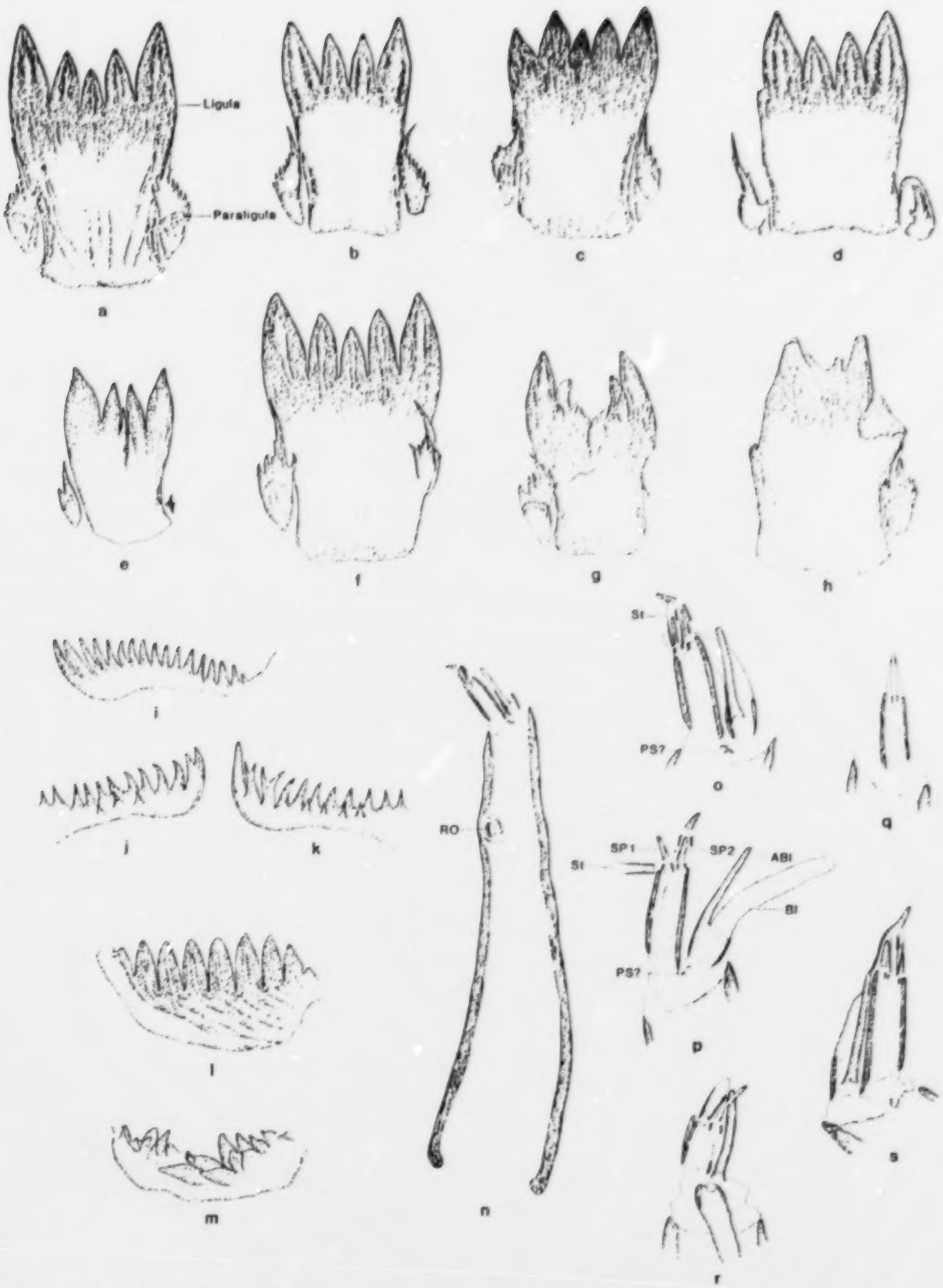

FIG. 13. Deformities in *Procladius* larvae: (a) normal ligula; (b–h) deformed ligula; (i) normal hypopharyngeal pecten; (j–k) deformed hypopharyngeal pecten; (l) normal hypopharyngeal comb; (m) deformed hypopharyngeal comb; (n) normal antenna (with segment enlargements o–p); (q–s) deformed antennae. BI, blade; ABI, accessory blade; St, style; PS, peg sensillum; RO, ring organ; SP, sensory pegs.

tion makes sense in view of the predatory life style of *Procladius*.

Antennal deformities in *Procladius* take much the same form as in *Chironomus*. In Fig. 13q, the apical segments have been replaced by one (or two?) transparent, wedge-shaped structures which lie behind the one remaining pedestal-mounted sensory

TABLE 2. Frequency (%) of types of deformities in *Chironomus* spp. larvae from Tobin Lake Sites 2 and 17.

	Site 2		Site 17	
	No.	%	No.	%
Number of larvae with deformed				
menta	103	21.1	23	14.9
mandibles	40	8.2	7	4.6
premandibles	23	4.7	3	1.9
antennae	22	4.5	19	12.3
epipharyngeal pecten	57	11.7	11	7.1
labral lamellae	22	4.5	2	1.3
labral setae	5	1.0	0	0.0

TABLE 3. Frequency (%) of single and multiple deformities in *Chironomus* spp. larvae from Tobin Lake Sites 2 and 17.

	Site 2		Site 17	
	No.	%	No.	%
Number of larvae with				
single deformities	145	29.8	35	22.7
double deformities	45	9.2	12	7.8
triple deformities	8	1.6	2	1.3
quadruple deformities	3	0.6	0	0.0
Total	201	41.3	49	31.8

TABLE 4. Severity (ISAD) of antennal deformities in *Chironomus* spp. larvae from Tobin Lake Sites 2 and 17.

	Site 2	Site 17
Number of *Chironomus* spp. larvae	487	154
Number of larvae with deformed antennae	22	19
Frequency of deformed antennae (%)	4.5	12.3
Number of evaluated larvae	21	19
Total IMR	264	205
Average IMR	12.6	10.8
ISAD	0.54 ± 0.25	1.33 ± 0.76

tube. The apical segments appear to be missing on the example in Fig. 13r, but more importantly, the wall of the second segment is incompletely sclerotized and a structure, possibly the accessory blade, is mounted sublaterally on the wall of the second segment. In Fig. 13s, the walls of the second, third, and fourth segments are partially fused.

2. Normal and deformed ligula and paraligua

The ligula of the Tanypodinae is a flexibly mounted stabbing mouthpart which replaces the mentum in other chironomid subfamilies. In normal *Procladius*, the ligula characteristically has five dark brown to black points arranged in a concave row (Fig. 13a). The paraligula are located at the base of the ligula and have a variable number of teeth, mainly along the outer margin.

Ligula with four teeth (Fig. 13b) probably represent the most common form of abnormal ligula. This configuration may proceed through the progressive loss of an outer tooth as suggested in Fig. 13c and 13d. The paraligula can also be reduced (Fig. 13e) or become fused to the ligula (Fig. 13f). The ligula in Fig. 13g is strongly deformed and has seven additional teeth for a total complement of 12 teeth. The massively deformed ligula in Fig. 13h is fused and the teeth blunted. The "tooth"

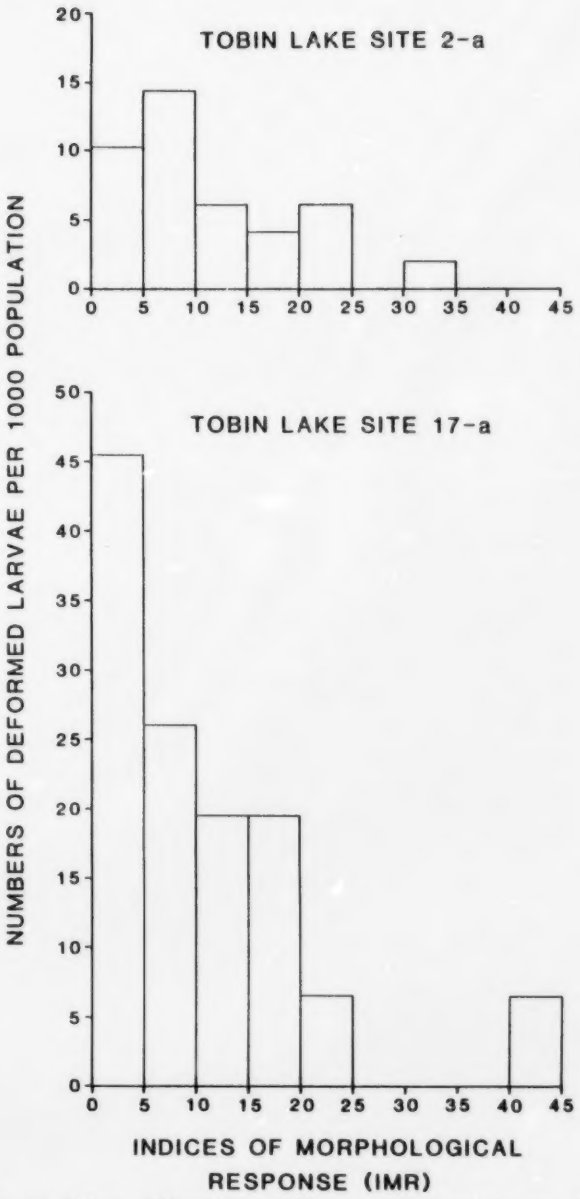

FIG. 14. Indices of Morphological Response in antennae by class for Tobin Lake Sites 2 and 17.

midway down the right side of the ligula probably represents the fused remnant of the right-hand paraligula.

3. Normal and deformed hypopharyngeal pecten

The hypopharyngeal pecten are a transverse row of (generally) 8–16 simple teeth or spines (Fig. 13i) mediobasal on the hypopharynx (Saether 1980). The deformed examples in Fig. 13j and 13k have bifid teeth in their complement.

4. Normal and deformed hypopharyngeal combs

The hypopharyngeal combs are a set of five to nine triangular-shaped teeth (Fig. 13l; dorsomental teeth sensu Roback 1980) on the prementohypopharyngeal complex. The comb in Fig. 13m has 17 teeth, many of which are superimposed over one another and irregular in size.

TABLE 5. Frequency (%) of types of deformities in *Cryptochironomus* sp. larvae from Tobin Lake Sites 2 and 17.

	Site 2		Site 17	
	No.	%	No.	%
Number of larvae with deformed				
menta	2	1.6	1	2.2
mandibles	1	0.8	0	0.0
premandibles	4	3.3	1	2.2
antennae	1	0.8	0	0.0
epipharyngeal pecten	0	0.0	1	2.2

TABLE 6. Frequency (%) of types of deformities in *Procladius* spp. larvae from Tobin Lake Sites 2 and 17.

	Site 2		Site 17	
	No.	%	No.	%
Number of larvae with deformed				
ligula	7	2.0	0	0.0
ligula/paraligula	2	0.6	1	1.0
antennae	3	0.9	0	0.0
hypopharyngeal pecten	4	1.2	1	1.0
hypopharyngeal combs	1	0.3	0	0.0

Occurrence of Characteristic Deformities

Structural Deformities in *Chironomus* spp. Larvae

The frequency of deformities in *Chironomus* spp. larvae was significantly higher at Site 2 (41.3%) than at Site 17 (31.8%). Chi-square analysis showed that the proportion of deformed to nondeformed larvae was significantly different at the two sites ($\chi^2 = 4.39$ where $\chi^2_{0.05,1} = 3.84$). The difference in the frequency of deformities probably reflects the difference in contaminant burdens impinging on the two reservoir sites.

The frequencies of deformities in different morphological structures were generally higher at Site 2 than at Site 17 (Table 2). The only exception was the antennae in which case the frequency of deformities was significantly greater at Site 17. Except for the antennae, the significance of the differences in the proportions of deformities in these other structures was generally less than 95%. Chi-square values for menta (2.86) and labral lamellae (3.37) were significant between 90 and 95% (where $\chi^2_{0.10,1} = 2.71$) and chi-square values for epipharyngeal pecten (2.57), mandibles (2.32), and premandibles (2.32) were significant between 85 and 90% (where $\chi^2_{0.15,1} = 2.18$). Although less easily interpreted, these results are surprisingly good for simple numerical data which include no estimates of severity of response.

The deformities in individual larvae were also separated according to single and multiple deformities (Table 3) and tested by chi-square. The difference in the proportions of single deformities was significant at about 95% ($\chi^2 = 3.65$ where $\sigma^2_{0.05,1} = 3.84$). None of the multiple combinations differed significantly.

Antennal Deformities

The only numerical data to show clear statistical differences were in the antennae (Table 2). According to chi-square, the proportions of deformed and nondeformed antennae in the two fauna were significantly different ($\chi^2 = 11.95$ where $\chi^2_{0.001,1} = 10.83$).

Antennal deformities were about 3 times more frequent at Site 17 than at Site 2, but the severity of deformities was greater at Site 2 (Table 4). According to Warwick (1985), the Index of Morphological Response (IMR) provides a measure of the severity of deformation in individual antennae. The distribution of IMR values in Fig. 14 shows that the greater proportion of deformities from Site 2 occurred in the higher response ranges, that is, in more severe IMR classes 6–10, whereas those from Site 17 occurred in less severe IMR classes 0–5. The difference in severity is further reflected in the average values for IMR (Table 4). The higher value at Site 2 agrees with the contention that the contaminant burden is greater at this site than at Site 17.

The distribution of individual IMR rankings from Sites 2 and 17 was compared using Cochran's modified *t*-test for dissimilar variances (Dixon and Massey 1969). The test indicated that within individual rankings the differences in severity were significant at about 95% ($t = 1.92$ where $t_{0.05,192} = 1.96$). For a single variable, this is quite good. It will be interesting to note as the various indices needed for an Index of Total Morphological Response (TMR) become available whether their inclusion will significantly improve these results and the ability of the test to accurately define differences between sites as Warwick (1985) suggested.

The values for the Index of Severity of Antennal Deformation (ISAD), a method developed by Warwick (1985) to assess the severity of deformities in larval antennae, were 0.54 and 1.33, respectively, for Site 2 and 17 (Table 4). At face value, these results appear to run contrary to the contention that Site 2 is the more seriously contaminated of the two sites. However, when interpreted in terms of quantal dose–response theory, as discussed below, the data do support the contention that Site 2 is the more seriously contaminated site.

Structural Deformities in *Cryptochironomus* spp. and *Procladius* spp. Larvae

The incidence of deformities in the different morphological structures of *Cryptochironomus* sp. larvae differed only marginally between Sites 2 and 17 (Table 5). In terms of severity, the only seriously deformed larva came from Site 2. The multiple deformities in this larva included a deformed mandible (Fig. 12i), a deformed antenna (Fig. 12g), and a deformed premandible (Fig. 12n). With this single exception, the deformities in the other larvae from both sites were single and relatively mild.

The incidence of deformities in the different morphological structures of *Procladius* spp. larvae also differed only marginally between Sites 2 and 17 (Table 6). In terms of severity, the more seriously deformed larvae came from Site 2. Although the severity of these has yet to be quantified, their distribution tends to support the contention that Site 2 is the most seriously contaminated of the two Tobin Lake sites.

Discussion

Few reports in the literature dealing with deformities in chironomid larvae describe these in detail. Klink (1984) presented an alphanumeric system for categorizing deformities in the teeth of the larval mentum. This is basically a cataloguing system and does not attempt to evaluate severity of deformation. Warwick (1985) formulated an indexing scheme for quantifying the severity of deformities in the antennae of the genus *Chironomus*. The index was left open-ended so that it (1) could be

adapted to the antennae of other species and (2) would eventually form part of a greater index including estimates of the severity of deformities in other structures of the larval head and body in an Index of Total Morphological Response.

The frequencies of deformities reported here for *Chironomus* spp. larvae from Sites 2 and 17 (41.3 and 31.8%, respectively) are high compared with values previously published in the literature. Two reasons may account for this: (1) the deformities listed here include many new structures for which deformities have never before been described and (2) the definition of deformities currently employed may include some individuals expressing normal rather than abnormal variation.

According to the definition presented in Warwick (1988), a morphological structure is considered deformed if its configuration departs from the normal. This definition is necessarily broad and all-inclusive because the boundaries between normal and abnormal variation have yet to be established for most morphological structures. The transition from normal to abnormal variation represents a continuum of response, and establishing the "limits of detection" for each structure may be important. Until suitable boundaries are established, however, some questionable examples probably will be included in estimates of frequency using the current definition.

As a case in point, the listings for deformed epipharyngeal pecten include a number of specimens displaying only very mild fusing between adjacent teeth (Fig. 10b, 10c). The question is whether these specimens are deformed or do they simply represent variants of normal structure. At the present time there is no satisfactory way to determine whether these are indeed true deformities. However, the problem may be alleviated in large measure when a satisfactory method for evaluating the severity of deformities in these structures can be established. It may be that epiphryngeal pecten are not good indicators of contaminant stress, but I suspect this is a case where simple frequency analysis is not adequate for evaluating stress response.

The importance of estimating severity of deformation is an integral part of estimating individual responses to contaminant stress. According to the National Research Council of Canada (1985), "percent response may show changes over time and space where mean response may not, (but) condensing data to this extent could cause loss of very important (response) information " (author's parentheses). Two sites with similar frequencies of deformities may be thought to be equally exposed to contaminants, but in actual fact may differ widely in the degree to which they are exposed. Without some means of dealing with the range or severity of response, the difference may go undetected and the real situation incorrectly assessed (National Research Council of Canada 1985).

One technique that is available for evaluating severity of response is ISAD. At first glance, the results for ISAD in this study seem to argue against the contention that Site 2 is the more heavily contaminated of the two Tobin Lake sites. The ISAD value for Site 2 (0.54) is lower than that for Site 17 (1.33), the less highly contaminated site. However, because n in the calculation of ISAD = $\Sigma IMR/n$ is based on the total number of specimens examined (i.e. the total larval population) rather than just the number of larvae with deformed antennae, the data must be interpreted in terms of quantal dose–response (Chan et al. 1984). It then becomes important to determine which side of the bell-shaped distribution curve each datum falls. If the datum for Site 2 is placed on the right-hand side of the distribution curve rather than on the left, the results then become consistent with the pattern shown by the frequency of deformities (41.3%) and the average value for IMR (12.6), both of which support the contention that Site 2 is the more seriously contaminated site, as common sense would dictate.

Warwick (1985) noted the same curiously inverted pattern in earlier work on Tobin Lake. In that study, lower ISAD values were found in areas of the reservoir where one would anticipate higher levels of contamination based on considerations of hydraulic energy and basin mechanics. Site VI, located in the deeper water area of the reservoir, might be expected to be more highly contaminated than Site V located between Site VI and the inflow area of the Saskatchewan River (Fig. 1). However, the ISAD value for Site VI (1.19) was lower than that (1.64) for Site V. As in the present study, the apparent contradiction can also be explained by quantal dose–response theory. If the two data points are positioned on the right-hand side of the quantal dose–response curve, Site VI then becomes the more contaminated of the two sites.

The placement of the datum from Site 2 on the right-hand side of the curve also explains in part the apparent inversion in the frequency of deformities in the antennae. Warwick (1985) noted that as the concentration of contaminants increased, response shifted from the antennae to other morphological structures. Placement of the ISAD datum on the right-hand side of the curve implies that the sensitivity of antennae is declining and response has begun to shift to the harder structures. This not only explains why the frequency of antennal deformities is lower at Site 2 (4.5%) than at Site 17 (12.3%), but also why the cumulative frequency of deformities is greater at Site 2 (41.3%) than at Site 17 (31.8%).

Acknowledgements

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References

BIRKHOLZ, D. A., M. R. SAMOILOFF, W. F. WARWICK, G. R. B. WEBSTER, AND J. WITTEMAN. 1980. The Tobin Lake project. Project proposal and progress report, November 1980. Office of Industrial Research, University of Manitoba, Winnipeg, Man. 110 p.

BODALY, R. A., D. M. ROSENBERG, M. N. GABOURY, R. E. HECKY, R. W. NEWBURY, AND K. PATALAS. 1984. Ecological effects of hydroelectric development in northern Manitoba, Canada: the Churchill–Nelson River diversion, p. 273–309. *In* P. J. Sheehan, D. R. Miller, G. C. Butler, and P. H. Bourdeau [ed.] Effects of pollutants at the ecosystems level. Sci. Comm. Pollut. Environ (SCOPE) 22. John Wiley & Sons, Chichester, New York, Brisbane, and Toronto.

CHAN, P. K., G. P. O'HARA, AND A. W. HAYES. 1984. Principles and methods for acute and subchronic toxicity, p. 1–51. *In* A. W. Hayes [ed.] Principles and methods of toxicology. Student Edition. Raven Press, New York, NY.

CURRY, L. L. 1958. Larvae and pupae of the species of *Cryptochironomus* (Diptera) in Michigan. Limnol. Oceanogr. 3(4): 427–442.

CUSHMAN, R. M. 1984. Chironomid deformities as indicators of pollution from a synthetic, coal-derived oil. Freshwater Biol. 14: 179–182.

DIXON, W. J., AND F. J. MASSEY. 1969. Introduction to statistical analysis. McGraw-Hill Book Co., London and New York. 638 p.

FRANK, C. 1983. Beeinflussung von Chironomidenlarven durch Umweltchemikalien und ihre Eignung als Belastungs- und Trophieindikatoren. Verh. Dtsch. Zool. Ges. 1983: 143–146.

HAMILTON, A. L., AND O. A. SAETHER. 1971. The occurrence of characteristic deformities in the chironomid larvae of several Canadian lakes. Can. Entomol. 103(3): 363–368.

HARE, L., AND J. C. H. CARTER. 1976. The distribution of *Chironomus (s.s.)? cucini* (*salinarius* group) larvae (Diptera: Chironomidae) in Parry Sound,

Georgian Bay, with particular reference to structural deformities. Can. J. Zool. 54: 2129–2134.

KLINK, A. 1984. Kopafwijkingen bij Chironomidae-larven onder invloed van chemische verotreiniging. Hydrobiologisch Adviesburo Klink, Wageningen. Rapp. Mededel. 12: 31 p.

KÖHN, T., AND C. FRANK. 1980. Effects of thermal pollution on the chironomid fauna in an urban channel, p. 187–194. *In* D. A. Murray [ed.] Chironomidae: ecology, systematics, cytology and physiology. Pergamon Press, Oxford and New York.

LINDEBERG, B., AND T. WIEDERHOLM. 1979. Notes on the taxonomy of European species of *Chironomus* (Diptera: Chironomidae). Entomol. Scand. Suppl. 10: 99–116.

MARGOLIS, L., G. W. ESCH, J. C. HOLMES, A. M. KURIS, AND G. A. SCHAD. 1982. The use of ecological terms in parasitology. (Report of an ad hoc committee of the American Society of Parasitologists.) J. Parasitol. 68: 131–133.

NATIONAL RESEARCH COUNCIL OF CANADA. 1985. The role of biochemical indicators in the assessment of ecosystem health — their development and validation. Associate Committee on Scientific Criteria for Environmental Quality. Natl. Res. Counc. Can. NRCC No. 24371: 119 p.

PERCY, J., K. L. KUHN, AND K. KALTHOFF. 1986. Scanning electron microscope analysis of spontaneous and UV-induced abnormal segment patterns in *Chironomus samoensis* (Diptera, Chironomidae). Roux's Arch. Dev. Biol. 195: 92–102.

ROBACK, S. S. 1980. The immature chironomids of the eastern United States IV. Tanypodinae–Procladiini. Proc. Acad. Nat. Sci. Phila. 132: 1–63.

SAETHER, O. A. 1980. Glossary of chironomid morphology terminology (Diptera: Chironomidae). Entomol. Scand. Suppl. 14: 1–51.

SAETHER, O. A., AND M. P. MCLEAN. 1972. A survey of the bottom fauna in Wood, Kalamalka and Skaha lakes in the Okanagan Valley, British Columbia. Fish. Res. Board Can. Tech. Rep. 342: 1–27.

SLIFER, E. H. 1970. The structures of arthropod chemoreceptors. Annu. Rev. Entomol. 15: 121–142.

TENNESSEN, K. J., AND P. K. GOTTFRIED. 1983. Variation in structure of ligula of Tanypodinae larvae (Diptera: Chironomidae). Entomol. News 94(4): 109–116.

WARWICK, W. F. 1980a. Palaeolimnology of the Bay of Quinte, Lake Ontario: 2800 years of cultural influence. Can. Bull. Fish. Aquat. Sci. 206: 117 p.

1980b. Chironomidae (Diptera) responses to 2800 years of cultural influence: a palaeolimnological study with special reference to sedimentation, eutrophication and contamination processes. Can. Entomol. 112: 1193–1238.

1980c. Pasqua Lake, southeastern Saskatchewan: a preliminary assessment of trophic status and contamination based on the Chironomidae (Diptera), p. 255–267. *In* D. A. Murray [ed.] Chironomidae: ecology, systematics, cytology and physiology. Pergamon Press, Oxford and New York.

1985. Morphological abnormalities in Chironomidae (Diptera) larvae as measures of toxic stress in freshwater ecosystems: indexing antennal deformities in *Chironomus* Meigen. Can. J. Fish. Aquat. Sci. 42: 1881–1914.

1988. Morphological deformities in Chironomidae (Diptera) larvae as biological indicators of toxic stress, p. 281–320. *In* M. S. Evans [ed.] Toxic contaminants and ecosystem health: a Great Lakes focus. John Wiley & Sons, New York, NY. 602 p.

WARWICK, W. F., J. FITCHKO, P. M. MCKEE, D. R. HART, AND A. J. BURT. 1987. The incidence of deformities in *Chironomus* spp. from Port Hope Harbour, Lake Ontario. J. Great Lakes Res. 13(1): 88–92.

WIEDERHOLM, T. 1984. Incidence of deformed chironomid larvae (Diptera: Chironomidae) in Swedish lakes. Hydrobiologia 109: 243–249.